



Digital Model-Based Engineering: Expectations, Prerequisites, and Challenges of Infusion

J.P. Hale

Marshall Space Flight Center, Huntsville, Alabama

P. Zimmerman and G. Kukkala (Contractor)

*Department of Defense, Office of the Deputy Assistant Secretary of Defense,
Alexandria, Virginia*

J. Guerrero

Department of Defense, U.S. Navy, Patuxent River, Maryland

P. Kobryn

Department of Defense, U.S. Air Force, Dayton, Ohio

B. Puchek and M. Bisconti (Contractor)

Department of Homeland Security, Washington, DC

C. Baldwin

Federal Aviation Administration, Morristown, New Jersey

M. Mulpuri

Department of Veterans Affairs, Indianapolis, Indiana

The NASA STI Program...in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- **TECHNICAL PUBLICATION.** Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- **TECHNICAL MEMORANDUM.** Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- **CONTRACTOR REPORT.** Scientific and technical findings by NASA-sponsored contractors and grantees.

- **CONFERENCE PUBLICATION.** Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- **SPECIAL PUBLICATION.** Scientific, technical, or historical information from NASA programs, projects, and mission, often concerned with subjects having substantial public interest.
- **TECHNICAL TRANSLATION.** English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results...even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI program home page at <<http://www.sti.nasa.gov>>
- E-mail your question via the Internet to <help@sti.nasa.gov>
- Phone the NASA STI Help Desk at 757-864-9658
- Write to:
NASA STI Information Desk
Mail Stop 148
NASA Langley Research Center
Hampton, VA 23681-2199, USA



Digital Model-Based Engineering: Expectations, Prerequisites, and Challenges of Infusion

J.P. Hale

Marshall Space Flight Center, Huntsville, Alabama

P. Zimmerman and G. Kukkala (Contractor)

*Department of Defense, Office of the Deputy Assistant Secretary of Defense,
Alexandria, Virginia*

J. Guerrero

Department of Defense, U.S. Navy, Patuxent River, Maryland

P. Kobryn

Department of Defense, U.S. Air Force, Dayton, Ohio

B. Puchek and M. Bisconti (Contractor)

Department of Homeland Security, Washington, DC

C. Baldwin

Federal Aviation Administration, Morristown, New Jersey

M. Mulpuri

Department of Veterans Affairs, Indianapolis, Indiana

National Aeronautics and

Space Administration

Marshall Space Flight Center • Huntsville, Alabama 35812

Acknowledgments

The Model-Based Systems Engineering (MBSE) Infusion Task team thanks the Interagency Working Group on Engineering Complex Systems for the opportunity to collaborate on this topic and to expand the thinking on uses of digital model-based engineering constructs.

Available from:

NASA STI Information Desk
Mail Stop 148
NASA Langley Research Center
Hampton, VA 23681-2199, USA
757-864-9658

This report is also available in electronic form at
<<http://www.sti.nasa.gov>>

EXECUTIVE SUMMARY

Digital model-based engineering (DMbE) is the use of digital artifacts, digital environments, and digital tools in the performance of engineering functions. DMbE is intended to allow an organization to progress from documentation-based engineering methods to digital methods that may provide greater flexibility, agility, and efficiency.

The term ‘DMbE’ was developed as part of an effort by the Model-Based Systems Engineering (MBSE) Infusion Task team to identify what government organizations might expect in the course of moving to or infusing MBSE into their organizations. The Task team was established by the Interagency Working Group on Engineering Complex Systems, an informal collaboration among government systems engineering organizations. This Technical Memorandum (TM) discusses the work of the MBSE Infusion Task team to date.

The Task team identified prerequisites, expectations, initial challenges, and recommendations for areas of study to pursue, as well as examples of efforts already in progress. The team identified the following five expectations associated with DMbE infusion, discussed further in this TM:

- (1) Informed decision making through increased transparency, and greater insight.
- (2) Enhanced communication.
- (3) Increased understanding for greater flexibility/adaptability in design.
- (4) Increased confidence that the capability will perform as expected.
- (5) Increased efficiency.

The team identified the following seven challenges an organization might encounter when looking to infuse DMbE:

- (1) Assessing value added to the organization. Not all DMbE practices will be applicable to every situation in every organization, and not all implementations will have positive results.
- (2) Overcoming organizational and cultural hurdles.
- (3) Adopting contractual practices and technical data management.
- (4) Redefining configuration management. The DMbE environment changes the range of configuration information to be managed to include performance and design models, database objects, as well as more traditional book-form objects and formats.
- (5) Developing information technology (IT) infrastructure. Approaches to implementing critical, enabling IT infrastructure capabilities must be flexible, reconfigurable, and updatable.
- (6) Ensuring security of the single source of truth.

(7) Potential overreliance on quantitative data over qualitative data. Executable/computational models and simulations generally incorporate and generate quantitative vice qualitative data.

The Task team also developed several recommendations for government, academia, and industry, as discussed in this TM. The Task team recommends continuing beyond this initial work to further develop the means of implementing DMBE and to look for opportunities to collaborate and share best practices.

TABLE OF CONTENTS

1. INTRODUCTION	1
1.1 Motivation	1
1.2 Team Membership	3
1.3 Digital Model-Based Engineering	5
2. PREREQUISITES: NECESSARY FOUNDATIONS FOR INFUSION	6
3. EXPECTATIONS	8
3.1 Developing Advocacy	9
4. CHALLENGES	13
5. RECOMMENDATIONS	14
6. CONCLUSION	15
BIBLIOGRAPHY	17

LIST OF FIGURES

1.	Current state of interactions	1
2.	Future state of interactions	2
3.	MBSE capability vector	6
4.	The ‘systems engineering problem’	9

LIST OF TABLES

1.	Expectations of infusion	8
2.	Challenges for infusion	13
3.	Recommendations for infusing DMbE	14

LIST OF ACRONYMS

AFLCMC	Air Force Life Cycle Management Center
AFSERC	Air Force Systems Engineering Resource Center
CASE	Center for Applied Systems Engineering
CBP	Customs and Border Protection
CONOPS	concept of operations
DASD(SE)	Deputy Assistant Secretary of Defense for Systems Engineering
DHS	Department of Homeland Security
DMbE	digital model-based engineering
DoD	Department of Defense
FAA	Federal Aviation Administration
FRD	Functional Requirements Document
IAWG	Interagency Working Group on Engineering Complex Systems
INCOSE	International Council on Systems Engineering
IP	integrated process
IT	information technology
JPL	Jet Propulsion Laboratory
KSA	knowledge, skills, and abilities
MBSE	model-based systems engineering
NAS	National Airspace System
NASA	National Aeronautics and Space Administration

LIST OF ACRONYMS (Continued)

NexGen	Next Generation Airspace System
PM	project management
R&A	requirements and architecture
ROI	return on investment
SE	systems engineering
SEDIC	Systems Engineering Development and Implementation Center
SETR	Systems Engineering Technical Review
TM	Technical Memorandum
U.S.	United States
VA	Department of Veterans Affairs

TECHNICAL MEMORANDUM

DIGITAL MODEL-BASED ENGINEERING: EXPECTATIONS, PREREQUISITES, AND CHALLENGES OF INFUSION

1. INTRODUCTION

1.1 Motivation

Within the International Council on Systems Engineering (INCOSE) Systems Engineering (SE) Vision 2025, “Systems Engineering focuses on ensuring the pieces work together to achieve the objectives of the whole.” The INCOSE vision extends the digital revolution and extends model-based approaches to enterprise-wide use.

In 2014, at the Jet Propulsion Laboratory’s (JPL) Model-Based Systems Engineering (MBSE) Symposium, NASA’s Chief Technologist, Dr. David Miller, briefed his view of model-based infusion with “MBSE: Harnessing Technology to Revolutionize NASA’s Engineering Practice.” Dr. Miller presented his perspective on the interactions among science, technology, and engineering disciplines (fig. 1).

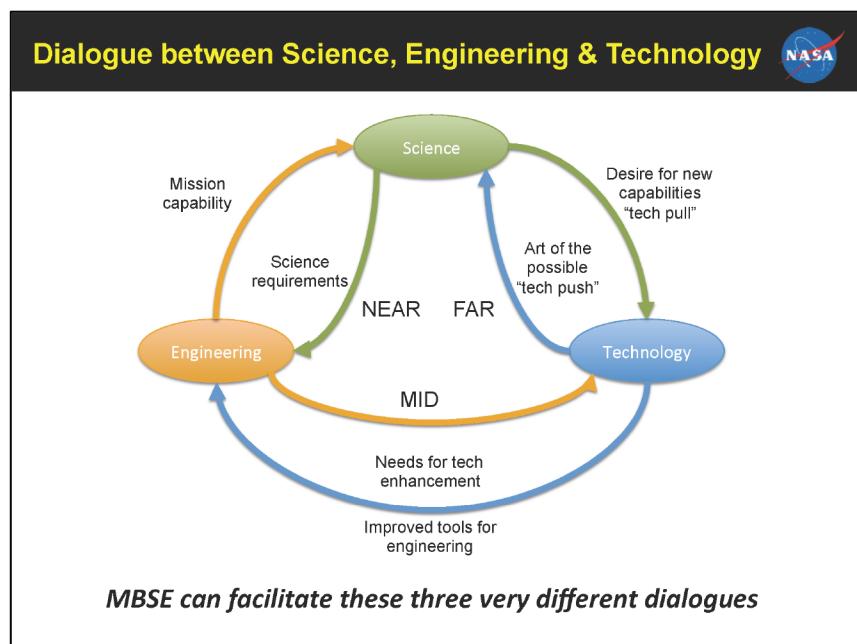


Figure 1. Current state of interactions.

Many members of the audience viewed this briefing as the first written indication from a senior leader within a federal agency regarding what leadership would expect from a wholesale shift to the method of model-centricity in systems engineering (fig. 2); e.g., what problems it might solve, what improvements it might make, and what advancements might be possible.

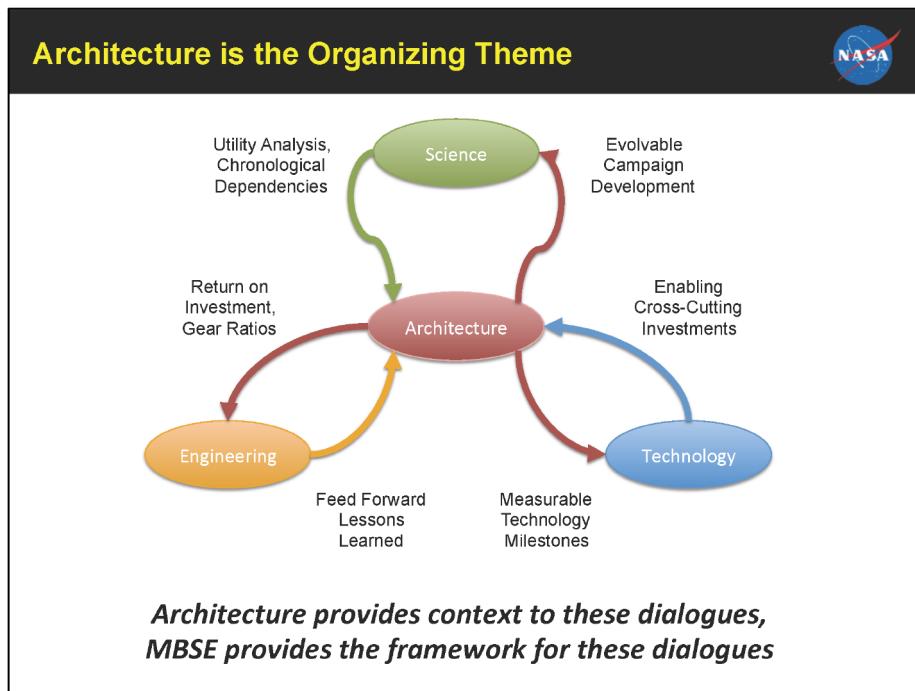


Figure 2. Future state of interactions.

Professional organizations, associations, and individual departments and agencies recognize the potential for using models combined with computing, or digital, environments. However, for many implementing organizations, adopting a new method or practice is difficult. They have successfully executed current methods and practices over many years, resulting in capabilities that have met or exceeded expectations. Disrupting the current practices with different methods could appear to put that success at risk, with potentially negative consequences for the taxpayer, system user, and recipient of the engineered item.

At the JPL symposium, a conversation ensued from Dr. Miller's presentation regarding how to aid in the adoption of MBSE across federal organizations with varying missions. It was evident from this discussion that leadership expectations were largely unknown. As a result, following the event, a group of the symposium participants approached the Interagency Working Group (IAWG) on Engineering Complex Systems to request support to articulate what the government would expect from the infusion of MBSE into their organizations.

The IAWG is an informal body of 10 civilian government systems engineering organizations that focuses on enhancing the practice of systems engineering. It serves as a forum for organizations to share activities, including both successes and failures, and to identify venues for technical exchanges and common areas of interest. The proposal submitted to the IAWG outlined the establishment of a task team to develop an initial list of expectations associated with MBSE infusion into the government. The IAWG approved the request and established the MBSE Infusion Task team on April 21, 2015.

1.2 Team Membership

The MBSE Infusion Task team included members from 5 of the 10 organizations that participate in the IAWG. Following are the Task team organizations' missions and the area of each organization that represents its interest in digital model-based engineering (DMbE):

- Department of Defense (DoD)

Mission: To provide the military forces needed to deter war and to protect the security of the country.

The Deputy Assistant Secretary of Defense for Systems Engineering (DASD(SE)) supports the development and growth of the defense system's engineering capability through engineering policy, continuous engagement with component systems engineering organizations, and technical engagement throughout the life cycle of individual defense acquisition program's adoption of digital MBSE as a DASD(SE) strategic goal.

- Department of Homeland Security (DHS)

Mission: To prevent terrorism and enhance security, manage U.S. borders, administer immigration laws, secure cyberspace, and ensure disaster resilience.

Relative to MBSE, the U.S. Customs and Border Protection (CBP) Systems Engineering Division, uses the Requirements and Architecture (R&A) Branch Integrated Process (IP) Guide to develop Functional Requirements Documents (FRDs) specifying the behavioral, performance, and nonfunctional requirements in order to acquire systems to protect the borders of the United States.

- Department of Veterans Affairs (VA)

Mission: To fulfill President Lincoln's promise "To care for him who shall have borne the battle, and for his widow, and his orphan" by serving and honoring the men and women who are America's veterans.

The Department of Veterans Affairs Center for Applied Systems Engineering (CASE) is an interdisciplinary Veterans Engineering Resource Center built on a philosophy of partnership between the Healthcare Systems Engineering faculty and Veterans Health Administration administrative and clinical management and staff, enabling the delivery of better patient care to veterans.

- Federal Aviation Administration (FAA)

Mission: To ensure the safest, most efficient airspace possible for generations to come.

At the enterprise level, systems engineering management integrates numerous interdependent FAA investment programs to advance the goals of safety and efficiency. At the program level, it optimizes performance, benefits, operations, and life cycle costs. Individual programs tailor the application of processes, tools, and techniques, according to the complexity of the program's requirements.

- National Aeronautics and Space Administration (NASA)

Mission: To drive advances in science, technology, aeronautics, and space exploration to enhance knowledge, education, innovation, economic vitality, and stewardship of the Earth.

The NASA Office of Chief Technologist has proposed a more formalized application of modeling, in an interactive modeling framework, to support system life cycle development to potentially enhance productivity and quality, reduce risk, improve communications, and enable more indepth independent assessment.

Each organization has a different purpose for employing systems engineering and therefore a different understanding of the potential of MBSE and its implementation. However, the organizations share some common perspectives and needs. For example, the DoD and DHS both view SE with the acquisition purview in mind, a perspective that derives from the traditional approach to developing a system. The VA and FAA also share a common type of mission, to deliver a safe, efficient, and effective service to the customers of their respective systems. NASA's mission is unique from that of the other organizations as it pursues the advancement and dissemination of knowledge, with a focus that stretches from Earth to the wide expanse of space. In all cases, the development of large and complex systems to enable successful programs requires rigorous execution of SE and integration processes.

1.3 Digital Model-Based Engineering

By agreeing to support the Task team, the members recognized a common need to move to a more model-based approach for completing engineering activities in support of their organizations' missions. The team began by establishing a term for the method. Among the organizations seeking to use model-centricity to execute the activities, a wealth of terms have been expressed to draw a level of understanding about the engineering activities from the title of the method itself. They considered existing terms, including 'model-based engineering,' 'model-based systems engineering,' 'model-based enterprise,' and 'model-based manufacturing,' all of which have their own meaning according to the organizations that apply them.

The team determined that a new general term and definition were necessary to articulate the use of systems engineering through models, engineering tools, methodologies, and digital environments without diminishing the quality and content of the resulting products and services. The team decided on 'digital model-based engineering' (DMbE) to reflect the expectations of infusing digital model-based methods into an organization. For the purposes of this Technical Memorandum (TM), DMbE is the use of digital artifacts, digital environments, and digital tools in the performance of engineering functions. DMbE is intended to enable practitioners to engineer capabilities using digital practices and artifacts in a collaborative environment, creating a digitally integrated approach with a federated single source of truth.

2. PREREQUISITES: NECESSARY FOUNDATIONS FOR INFUSION

Prerequisites for the infusion of DMbE include management support/advocacy, technical capability readiness, and organizational/cultural willingness (or lack of resistance) to adopt a new methodology.

Some level of management support is essential, and having a management champion or advocate is better still. This support may be gained through education and exposure to examples and benefits of DMbE. Encouraging and facilitating organizational and cultural change is often a challenge. Education, training, and access to the necessary tools, applications, and aids can be helpful. In general, lowering barriers to adoption and implementation is necessary. Helpful in all these cases is a clear statement or vision of a future state of the use of DMbE and of the approach or roadmap aligned with the vision going forward to identify avenues of infusion into normal business activities.

Figure 3 illustrates a framework for conceptualizing technical capability readiness in three elements or axes, with the Capability vector comprised of components defined along each of the three axes.

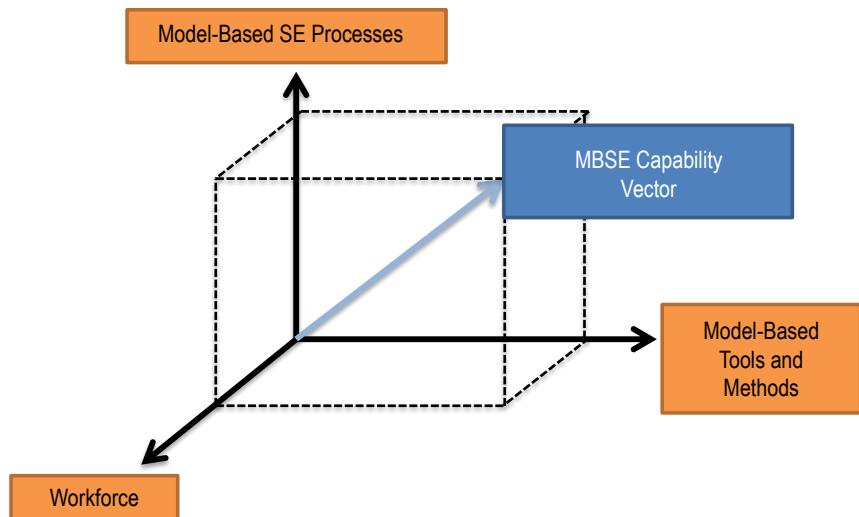


Figure 3. MBSE capability vector.

The first axis, Model-Based SE Processes, implies a solid foundation in SE processes. Before any organization can infuse DMBE, the organization must have a codified SE process in place. This will ensure the organization understands what needs to be done through the development of a system at a foundational level. Having an SE process in place will also provide a general rationale as to what activities need to be completed and why.

The second axis, Model-Based Tools & Methods, relates to the tools and methods for digital modeling and analysis supporting the SE processes. Transitioning an organization from a document-based SE methodology to a model/data-centric methodology does not alter the underlying, well-understood SE processes. A DMBE methodology merges the best practices of SE with the use of modeling. This axis includes the enabling information technology (IT) infrastructure to effectively manage the organization's information environment. It provides identification, management, interoperability, and integration of information across programmatic and technical domains.

The third axis, Workforce, relates to the knowledge, skills, and abilities (KSAs) of the technical workforce. Like the Model-Based SE Processes axis, the Workforce must have solid KSA associated with the SE processes as a prerequisite to moving on to model-based KSA.

There needs to be some balance across the three axes to advance along the Capability Vector. For example, advancing too far up the Tools & Methods axis without increasing the Workforce KSA would prove difficult. Likewise, training the workforce without first advancing model-based processes would be difficult.

Organizations interested in infusing DMBE must recognize and identify the need and must be willing to make the necessary changes in established processes, tools and methods, and workforce. This results in a multifaceted approach that begins with the recognition that a change will have a positive outcome in the resultant capability, the staff makeup, and/or the speed of execution, with the expectation of higher precision and discovery of defects early on in a project's life cycle. In other words, transition is a process, not an event.

It is understandable that the multifaceted approach will have to be planned and will not occur instantaneously. A willingness to change is accompanied by planning for the transition, identification of the stakeholder population among the adopters, and the understanding of what a successful change looks like.

3. EXPECTATIONS

A common theme in developing anything is to know when you are done—to know ‘what right looks like.’ Use of DMbE within an organization is similar. From the definition, we infer that DMbE is intended to enable practitioners to engineer capabilities using digital practices and artifacts in a collaborative environment, creating a digitally integrated approach that uses a federated single source of truth to evolve complex systems. To help illustrate this intended end state, the Task team developed a sample of five expectations (table 1) an organization might have regarding the potential benefit or result of incorporating DMbE.

Table 1. Expectations of infusion.

No.	Expectation	Rationale
1	Informed decision making through increased transparency and greater insight	Transparency is important for decision makers as complex systems progress through their decision processes, ranging from approval of new capabilities to deploying systems in the field. Increased transparency, with the right controls, to allow better control of scope as a balance mechanism in the decision process. DMbE also enables decision makers to have greater insight into the results of their decision (e.g., system results) and better understand the technical and nontechnical drivers.
2	Enhanced communication	One of the greatest challenges in any development is understanding the problem space to define the constraints, requirements, etc. to ensure that the message is consistent as it moves through the decision processes. Enhancing communication will help reveal ways to widen the boxes across the four aspects shown in figure 4, resulting in a clearer definition of the requirements that can address the larger area of the problem space.
3	Increased understanding for greater flexibility/adaptability in design	Desired capability in mind, in some cases taking more than a decade to develop, test, and field. This approach has resulted in a static development process with restrictions on how far a system can go in delivering the desired capability. The growing environment of rapid technological change calls for a development methodology that allows and empowers the system developers and decision makers to understand the ripple effects of changes to the capability and adapt to those changes at a much faster rate. Organizations need to understand more quickly the limits of a system and how much a proposed capability can adapt to the operational environment outside the established parameters.
4	Increased confidence that the capability will perform as expected	The complexity of systems acquired by the government is growing at a tremendous rate. Software has become a critical factor contributing to the growing complexity, as a majority of the capabilities provided by a system depend on the software telling the hardware what to do. Using an approach that allows viewing the system under development from various perspectives provides the government with greater confidence that the complexity is well managed and consistent. It also ensures that the customer/user is able to use the capabilities of the end item to the greatest extent possible. This expectation ensures that the end item is developed with improved quality through better management of complexity, control of scope, communication, risk reduction, etc. Quality is essential in delivering a capability that focuses on the customer's/user's experience and ability to use the developed capability in the operational environment.
5	Increased efficiency	This expectation is consistent with enhanced communication and also involves the processes that enable efficiency. The government seeks to reduce the cycle time and effort necessary to communicate, manage, and execute the processes to develop complex and noncomplex systems, as well as to enable follow-on development from artifacts resulting from DMbE.

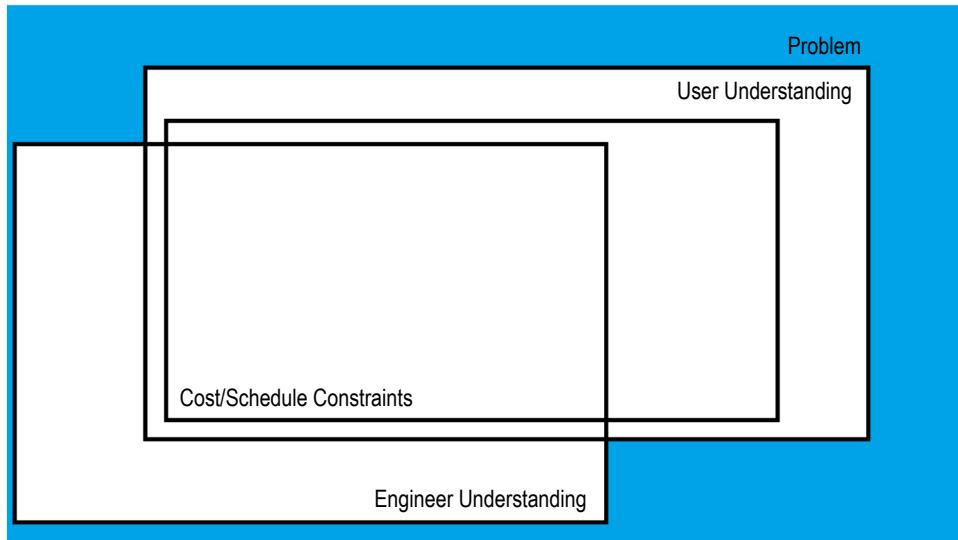


Figure 4. The ‘systems engineering problem.’

3.1 Developing Advocacy

Below are examples of several efforts by the Task team organizations to understand and outline aspects of DMbE.

- **DoD**

The Military Departments and Agencies have demonstrated many efforts to infuse DMbE into their organizations. As one example, Naval Air Command’s Systems Engineering Development and Implementation Center (SEDIC) has begun developing a model-centric systems engineering Web-based environment intended to increase the effectiveness and efficiency of technical reviews. They have deployed the Systems Engineering Technical Review (SETR) Manager tool, which enhances technical collaboration and empowers program offices, through robust information and knowledge exchange, with improved rationality for key programmatic decisions. The tool also serves as a checklist and uses social media-like functionality to ensure the right engineering functions are being applied and completed at the right time. The Center used a ‘going viral’ strategy to deploy the SETR Manager without the need for marketing or any significant user training. After approximately 1 year in deployment, the SETR Manager has reached nearly 3,000 users and has collected more than 300,000 data points across the Naval Air Systems Command’s acquisition portfolio, which the SEDIC intends to use to identify trends on various levels.

As another example, the Air Force Materiel Command’s Air Force Life Cycle Management Center (AFLCMC) recently stood up the Air Force Systems Engineering Resource Center (AFSERC) to make model-based systems engineering tools readily available to the engineering workforce. Building upon the success of the Navy’s Systems Engineering Resource Center,

AFSERC provides a Web-based environment for users to access and use MBSE tools. The user base for AFSERC has grown sixfold in its first year of operation and is expected to continue to grow. Additionally, AFLCMC recently partnered with the Air Force Research Laboratory, the Air Force Institute of Technology, and MITRE to host an MBSE symposium aimed at bringing early MBSE adopters and thought leaders together. The symposium is the first step in forming a partnership to advance the use of MBSE tools and processes, and increase the technical competencies of the organic workforce in MBSE.

DoD, through the Office of the Deputy Assistant Secretary of Defense for Systems Engineering, initiatives are working internally and externally to establish a strategy, identify digital artifacts, develop training material, etc., as a means to advance the state of practice for digital engineering within the DoD.

- DHS

Within DHS, CBP's Systems Engineering Division is implementing DMbE (model-based systems engineering) early in the systems engineering life cycle using a tool with a shared license enterprise version so it is readily accessible to systems engineers. They perform Mission and Operational Analysis to capture concept of operations (CONOPS) activities and further decompose the CONOPS with use case analyses, resulting in complete coverage of required operational capabilities, which are then captured in the Operational Requirements Document. Once these activities are specified, they expand the model with the Systems Engineering R&A IP, which takes the operational artifacts and adds content with the system perspective. They use SysML to create the system's content from behavioral, structure, and performance analyses. They then use the model to auto-generate the FRD, which contains derived use case scenarios, logical structural decomposition (logical components with performance and functions included), states of the system, nonfunctional requirements captured in textual packages, and functional requirements. This model-based, holistic approach yields an FRD that prospective contractors can better understand, delivering a proposed solution that more closely fulfills the end user's needs, requirements, and expectations.

- VA

In an effort to reconcile diverging perspectives across different engineering disciplines, the VA CASE reached out to three systems engineering practitioner groups within the VA: Civil Engineering, Policy Analysis, and Operations Management. Each group elected engineering leads to develop their discipline's vision of a DMbE future. First, the leads developed their vision, which spanned key processes and tools employed through systems engineering activities. Second, the practitioner groups compared the current state of processes and tools with the future state to identify discipline-specific expectations for DMbE. Finally, they identified the VA's cross-cutting expectations for DMbE from a practitioner's perspective.

- FAA

The FAA is creating a Model-Based Systems Engineering Roadmap as a plan for developing the Next Generation Airspace System (NextGen). The complexity of NextGen makes it difficult to predict how new systems will react when integrated into the existing National Airspace System (NAS). Currently, the organizations within the NextGen office use a combination of text- and model-based artifacts to develop requirements for new systems. Expectations for DMbE are better requirements and the ability to explore how new systems will interact before integration into the NAS. The roadmap will provide near-term objectives and a long-term vision to alter the way new systems are envisioned and specified. In the near term, changes should make better use of existing models for developing requirements. In the long term, a true DMbE approach is envisioned where new systems are described via graphical models and concepts are validated via simulations.

- NASA

NASA has implemented aspects of DMbE on more than three dozen flight programs/projects at more than two-thirds of its Flight and Research Field Centers, addressing various aspects of the product life cycle from mission and hardware development through validation, verification, and operations. For example:

- The Europa mission, a detailed reconnaissance of Jupiter’s moon, Europa, used DMbE for mission concept definition, including all systems engineering activities (requirements derivation, justification, traceability, analysis, maturity, history, verification, document generation, metrics, etc.).
- The Asteroid Redirect Robotic Mission, a robotic mission to visit a large near-Earth asteroid to collect a multi-ton boulder from its surface, focused on a minimum set of DMbE capabilities required to mature the concept in phase A (e.g., Requirements, Operations Concepts, Product Breakdown Structure, and System Block Diagrams).
- The NASA Engineering and Safety Center has used DMbE on roughly a dozen assessment activities ranging from interface definition to detailed studies on validation and verification of high-risk, high-value flight systems.

Numerous DMbE training and pathfinder efforts are also underway at both the Center and Agency levels. For example:

- Participants in SE and project management (PM) development programs use DMbE to design ‘real-world’ projects, including developing all SE/PM deliverables and conducting paperless, model-based milestone reviews.
- A partnership among the Office of Chief Engineer, the Agency’s Systems Engineering Technical Fellow, and the Office of Chief Information Officer, is defining functional requirements and solution approaches for a federated information model of disparate, heterogeneous data sources.

- A NASA Pathfinder effort, led by the SE Technical Fellow, is evaluating various digital threads on challenging NASA problems across the system's life cycle. Best practices are being captured for next steps in implementation. The effort is also piloting a cross-Center, cloud-based collaborative environment. Nine of ten NASA Centers are involved in the activity.

NASA integrates aspects of DMbE within a strong framework of systems engineering as a means to improve products, technical decisions/solutions, and efficiency.

4. CHALLENGES

Each organization needs to manage its expectations of DMbE with the understanding that challenges must be overcome for expectations to be met.

The Task team identified several potential challenges that organizations may encounter when infusing DMbE. Table 2 lists some of these challenges, along with ideas for mitigating them. This list should not be viewed as exhaustive, nor is each challenge applicable to each organization. As they incorporate DMbE, organizations may find additional challenges and may adopt methods for addressing them that are either sharable with other members of the IAWG or specific to their own adoption process.

Table 2. Challenges for infusion.

No.	Challenge	Potential Mitigation
1	Assessing value added to the organization: – Not all DMbE practices will be applicable to every situation in every organization, and not all implementations will have positive results.	Establish valid metrics to monitor progress and assess the value (e.g., return on investment (ROI) in implementing DMbE. This will allow adjustment of implementation activities.
2	Overcoming organizational and cultural hurdles: – Resistance to adoption. – Barriers to adoption and implementation.	Provide education, training, and access to the necessary tools, applications, and aids to keep skills fresh and transfer knowledge.
3	Adopting contractual practices and technical data management: – Regulatory and statutory elements supporting current practices. – Technical data management processes as currently instantiated, which dwell on the format absent of content.	Revise regulatory and statutory language to enable and foster use of digital artifacts and processes. Permanently establish technical capabilities to enable bidirectional exchange among, or access to, the full range of levels of models and databases.
4	Redefining configuration management: – The DMbE environment changes the range of configuration information to be managed to include performance and design models, database objects, as well as more traditional book-form objects and formats.	Develop needed enabling capabilities including snapshots of baselines, version releases and freezes, and status and account metrics and reports for each identified configuration item.
5	Developing IT infrastructure: – Approaches to implementing critical, enabling IT infrastructure capabilities must be flexible, reconfigurable, and updatable.	Establish accessibility to, and interoperability among, disparate, heterogeneous tools, models, and other data sources for critical, enabling capabilities.
6	Ensuring security of the ‘single source’ of truth.	Identify appropriate access control needed to ensure protection of classified and controlled unclassified data. Ensure access to long-term and archival data and models.
7	Potential overreliance on quantitative data over qualitative data: – Executable/computational models and simulations generally incorporate and generate quantitative versus qualitative data.	Properly assess the quantitative results to give them the appropriate weight in subsequent decision making.

5. RECOMMENDATIONS

The expectations outlined in this TM highlight a demand for the ability to have better, faster, and more complete communication among users of DMbE as it is infused into an organization to facilitate the development of a system. As illustrated in figure 3, it is important to establish and build upon the necessary foundations as we move forward. To this end, the Task team developed five recommendations (table 3) identifying opportunities to engage and develop ways to infuse DMbE into organizations.

Table 3. Recommendations for infusing DMbE.

No.	Challenge	Potential Mitigation
1	Conduct a study to understand how contractual language influences current acquisition and engineering processes with regard to the exchange of electronic data and models among various types of organizations (e.g., government-government boundary and government-industry boundary) and what kind of impact DMbE would have on the relationships. The results from the study should also identify what configuration items need to be addressed in the contractual language.	Many legacy statutes, regulations, and guidance were developed when the written, paper documentation was the state of the art. In the shift to digital artifacts, it is appropriate to reexamine the applicability of U.S. statutes, regulations, and guidance for changes that must be accommodated both to take advantage of the digital artifacts and to ensure their usefulness and applicability.
2	Identify best practices/framework necessary to convey the technical accuracy, precision, and uncertainty of data/information sufficient for subsequent, unambiguous, interpretation and use.	The shift from the written word to digital artifacts enables the transmission of more complete and complex information. To reduce misinterpretation or ambiguity, it is necessary to describe the data that will be exchanged so that organizations can determine intended use, assumptions, constraints, boundaries, limits of use, etc.
3	Identify metrics that highlight how an organization can qualify/quantify its ROI in DMbE (will vary based on project/program).	Practitioners may be skeptical of the shift from a 'validated' method of developing a system to an unverified and invalidated development methodology. To provide the evidence necessary to show value from the shift, it is important to identify two types of metrics for ROI: (1) metrics on the end product/system and (2) metrics on the effectiveness of the methodology itself. Metrics on the end product should verify that the need statement is addressed, while the metrics on the effectiveness of the methodology are intended to validate that DMbE does work.
4	Develop a well-defined process to identify when/where to employ DMbE (ensure tailorability). Rather than attempt a complete shift, consider staging the transition. Identify a common activity or process and make a determination of how that activity would occur with digital artifacts rather than written ones. When feasible, incorporate existing processes that already use digital artifacts.	Organizations may desire a wholesale shift to digital artifacts as the means of technical communication about a process, or physical item, but that shift is not easy. In order to build a complete transition, it will be necessary to identify items that are not part of the projected transition but rather support the transition (e.g., new configuration management processes).
5	Establish a follow-on task team to identify forums for implementers/users of DMbE to identify and share best practices, gaps, and tools for cross-platform/cross-Agency use, and build/update a calendar to maintain situational awareness.	Model based is a hot topic that would generate interest in a range of topic areas and sponsored events. Proposing to the IAWG executives to form a new Task team would allow more participants to bring their perspectives to the initiative as well as indicate the importance of the request.

6. CONCLUSION

The MBSE Infusion Task team supports incorporating DMbE into the systems engineering practices of government organizations and likewise encourages academia and industry to look for DMbE opportunities. DMbE allows organizations to progress from former document-based methods to digital methods that enable greater flexibility, agility, and efficiency. The Task team identified initial challenges and recommendations for areas of study to pursue as well as examples of efforts already in progress. The team recommends continuing with additional efforts to refine DMbE infusion techniques that advance digital capabilities within organizations, and to identify opportunities to exchange ideas and best practices.

Inquiries regarding this TM may be directed to the following organization:

Office of the Deputy Assistant Secretary of Defense
Systems Engineering
3030 Defense Pentagon
3C167
Washington, DC 20301
osd.atl.asd-re.se@mail.mil

BIBLIOGRAPHY

Federal Aviation Administration, “FAA Systems Engineering Manual,” Version 1.1, Federal Aviation Administration, <<https://sep.faa.gov/file/get/2974>>, September 11, 2015.

Federal Aviation Administration, “Performance—National Airspace System,” <<http://www.faa.gov/nextgen/snapshots/nas/>>, 2015.

Fisher, A.; Friedenthal, S.; Sampson, M.; et al.: “Model Lifecycle Management for MBSE,” INCOSE International Symposium, Las Vegas, NV, <http://www.omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:model_lifecycle_management_for_mbse_v4.pdf>, 2014.

International Council on Systems Engineering, “Systems Engineering Vision 2025,” INCOSE, <<http://www.incose.org/docs/default-source/aboutse/se-vision-2025.pdf?sfvrsn=4>>, 2014.

Keating, C.B.; and Ireland, V. (Eds.): “Complex System Governance Editorial,” *International Journal of System of Systems Engineering* (Inderscience Enterprises Inc.), Vol. 7, No. 1/2/3, 2016.

Long, D.: “4 Myths and Misconceptions of MBSE,” <<http://community.vitechcorp.com/home/post/4-Myths-and-Misconceptions-of-MBSE.aspx>>, May 1, 2015.

Miller, D.W: *MBSE: Harnessing Technology to Revolutionize NASA’s Engineering Practice*, Pasedena, CA, January 2015.

National Aeronautics and Space Administration, “What Does NASA Do?” <https://www.nasa.gov/about/highlights/what_does_nasa_do.html>, November 2015.

National Defense Industry Association, Systems Engineering Division, Models and Simulations, “Final Report of the Model Based Engineering (MBE) Subcommittee,” February 10, 2011.

National Institute of Technology, National Institute of Standards and Technology Technical Note 1753, “Model Based Enterprise/Technical Data Package Summit Report,” <<http://dx.doi.org/10.6028/NIST.TN.1753>>, 2012.

Office of the Deputy Assistant Secretary of Defense for System Engineering, “About Systems Engineering,” <<http://www.acq.osd.mil/se/mission.html>>, July 16, 2014.

Reedy, J.; Lunzman, S.; and Mekari, B.: “Model-based design accelerates development of mechanical locomotive controls,” SAE International, <<http://articles.sae.org/9422/>>, February 10, 2011.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
<p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operation and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</p>				
1. REPORT DATE (DD-MM-YYYY) 01-07-2017		2. REPORT TYPE Technical Memorandum	3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Digital Model-Based Engineering: Expectations, Prerequisites, and Challenges of Infusion		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S) J.P. Hale, P. Zimmerman (Office of the Deputy Assistant Secretary of Defense),* G. Kukkala (Contractor),* J. Guerrero (U.S. Navy),** P. Kobry (U.S. Air Force),*** B. Puchek,† M. Bisconti (Contractor),† C. Baldwin,‡ and M. Mulpuri†		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) George C. Marshall Space Flight Center Huntsville, AL 35812		8. PERFORMING ORGANIZATION REPORT NUMBER M-1435		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001		10. SPONSORING/MONITOR'S ACRONYM(S) NASA 11. SPONSORING/MONITORING REPORT NUMBER NASA/TM—2017-219633		
12. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified-Unlimited Subject Category 31 Availability: NASA STI Information Desk (757-864-9658)				
13. SUPPLEMENTARY NOTES Prepared by the Chief Engineers Office, Engineering Directorate *Dept. of Defense, Alexandria, VA, **Dept. of Defense, Patuxent River, MD, ***Dept. of Defense, Dayton, OH, †Dept. of Homeland Security, Washington, DC, ‡Federal Aviation Administration, Morristown, NJ, ¶Dept. of Veterans Affairs, Indianapolis, IN				
14. ABSTRACT Digital model-based engineering (DMbE) is the use of digital artifacts, digital environments, and digital tools in the performance of engineering functions. DMbE is intended to allow an organization to progress from documentation-based engineering methods to digital methods that may provide greater flexibility, agility, and efficiency. A Model-Based Systems Engineering (MBSE) Infusion Task team was established by the Interagency Working Group on Engineering Complex Systems to identify what government organizations might expect in the course of moving to or infusing MBSE into their organizations. The Task team identified prerequisites, expectations, initial challenges, and recommendations for areas of study to pursue, as well as examples of efforts already in progress. These are discussed further in the body of this Technical Memorandum.				
15. SUBJECT TERMS systems engineering, model-based systems engineering, model-based engineering, digital model-based engineering, model-centric engineering				
16. SECURITY CLASSIFICATION OF: a. REPORT U		17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 32	19a. NAME OF RESPONSIBLE PERSON STI Help Desk at email: help@sti.nasa.gov
b. ABSTRACT U				19b. TELEPHONE NUMBER (Include area code) STI Help Desk at: 757-864-9658

National Aeronautics and

Space Administration

IS02

George C. Marshall Space Flight Center

Huntsville, Alabama 35812

